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Demonstrating the lessons learned for Lightweighting EV components through a circular economy approach using eco-design methodology

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Executive Summary

LEVIS is an innovation project funded by the EU Horizon 2020 program. Its main objective is to demonstrate the technical, operational and economic feasibility of applying eco-design and circular economy principles into the development of lightweight bio-based materials and carbon fibre thermoplastic composites for electric vehicle components. The project demonstrates the application of these materials on four case studies: a suspension control arm, a battery box, a battery module and a cross car beam. Lessons learned from the development of the materials and the manufacturing processes of the components are presented.

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1 Introduction to LEVIS: Circularity in the automotive sector

Circular Economy is becoming an increasingly important and strategic topic for the Automotive industry. Resource scarcity, manufacturing and operational costs and sustainability are key drivers for this development.

Since the weight influences the energy efficiency and the range of vehicle, lightweighting becomes an important factor for faster market growth of Electric Vehicles (EVs), contributing to targeted greenhouse gas emissions reduction by 2050 [1]. Meanwhile, the European Union implemented regulations that shape environmental, social and circular economy requirements relevant for the automotive industry, and more are under development. [2].

We are demonstrating the feasibility of circularity in the automotive sector through the EU funded project LEVIS. LEVIS has developed multi-material solutions based on bio-based materials and carbon fibre thermoplastic composites optimally integrated with metals, produced using cost-effective and scalable manufacturing technologies. The partners demonstrate these new technologies by the using the materials in four EV components: A suspension control arm, a battery box, a battery module and a cross car beam:

- A suspension control arm, which is used to allow the wheel to move along the vertical axis – shaking the suspension - and to rotate around it when steering.
- A battery box, which contains the battery modules and protects them during operation and in case of an accident. It also supports the modules by integrating them within the vehicle frame and has an important role in safety.
- A battery module housing, the module housing is a mechanical casing for the cells. The housing’s main function is to thermally, mechanically, and electrically protect the cells and make sure there is electrical distribution through the busbar system.

- A cross car beam, which is a structural component in the dashboard area. The primary function is to provide the structure for the dashboard and all the sub-systems that constitute the IP module (steering column, HVAC, air- bags, EE units).

2 Methodology

2.1 Application of eco-design

To make effective circular design decisions, an eco-design methodology is applied in the early stages of the design process (Fig. 1.). A toolkit (iEDGE - integrated Eco-Design Guideline and Evaluator) has been developed to aid the decision-making for product design and manufacturing by applying circular economy principles. By considering economic, environmental, social, and technical parameters, designers are able to justify balanced design decisions based on Key Performance Indicators (KPIs) and high-level requirements across these parameters. The toolkit itself contains 5 steps which has to be followed:

1. **Frame the context** of the design environment by setting objectives and choosing a benchmark product.

2. **Identify scope and (high-level) requirements**. This is done by using the RiT (Requirements identifier Tool) checklist to guide the brainstorm session in finding potential impact related concerns and bottlenecks of the benchmark product. From the RiT Checklist high-level requirements and corresponding (KPIs can be formulated. In addition, the EQFD (Eco-design Quality Function Deployment) tool is used to set priorities for KPIs. These priorities rankings are used later in the performance evaluation.

3. **Create a baseline and set a target**. The performance evaluation tool (located in the EQFD sheet) is used to score the benchmark performance and to set the target. This input is used by the tool to automatically provide a suggested strategy and KPIs to focus your improvement direction on.

4. Create **an inventory of improvement options** and performing a **feasibility assessment.** The inventoried improvement options are analyzed for their effects on different life cycle phase and impact areas, which results in low or high-risk improvement options. The feasibility assessment is then performed to determine whether the improvement is suitable for the new design or not.

5. **Performance Evaluation** of the new design. The new design uses the same performance evaluation tool as the benchmark product and target. This results in a visual overview of the performances in a radar chart.

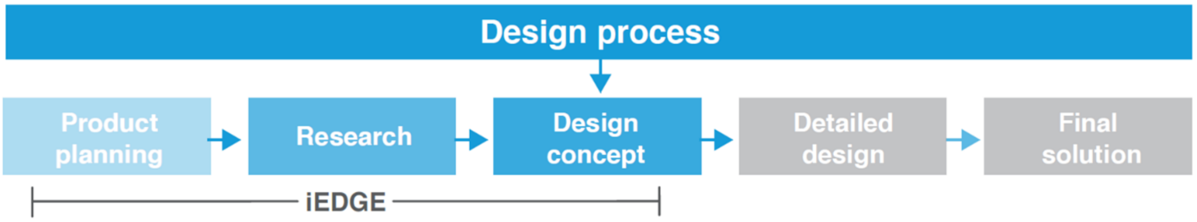


Figure1: Eco-Design methodology

The iEDGE toolkit has been applied by the four demonstrator industrial partners and their feedback has been used to identify challenges and lessons learned about the use of eco-design during the project.

2.2 Materials & Processes

LEVIS has developed new materials using novel manufacturing processes that improve circularity in material use and energy efficiency. Advanced testing and simulation models are used to ensure failure and fatigue performances match or exceeds those for conventional materials and processes. Sensor technologies are developed to monitor components on structural integrity and reliability during service life.

The technologies developed by LEVIS that would contribute to the circularity, material use and energy efficiency will be explained below.

2.2.1 Bio-based and recycled carbon fibers and acrylic based resin

The aim is to develop structural parts in automotive using hybrid solutions made of carbon fiber reinforced thermoplastics (CFRP) and metal. Recyclable resins, bio-resourced CF and recycled CF are being developed and used for the automotive parts for enhanced sustainability. Ex-cellulose carbon fibers are being developed at the pilot-scale and the objective is to upscale ex-cellulose CF production. The assessment for the state of the art and the aimed technology readiness level (TRL) was deemed to go from TRL 3-4 to 5-6 for both the fibers and the acrylic based resin"

2.2.2 Composite manufacturing technology

Resin Transfer Moulding (RTM) involves the injection of a monomer and a catalyst into a closed mold containing a reinforcement material, resulting in a polymerization in-situ. The focus in this project is on using novel polyamide or acrylic-based resin, along with bio-based carbon fiber, and optimizing the mechanical performance by using specific sizing compositions for each resin. The preforming stage is also being addressed to meet productivity targets, with automated tape layering (ATL) technology requiring binder development that is compatible with TP matrices, RTM processes, and heating sources from the ATL head.

Compression molding of sheet molding composites (SMC) allows production of high strength complex parts. It consists on molding a chopped or continuous reinforced prepreg sheet through compression. Compression moulding will be used in the project for the battery moulding housing. Since this part presents lower mechanical properties, short chopped carbon fibers can be used. Also, recycled carbon fibers and bio-based carbon fibres are foreseen to be used in order to decrease the carbon footprint.

2.2.3 Metal and thermoplastic composites (hybrid technology)

Multi-material design concepts aim to optimize performance while minimizing costs. However, current solutions based on thermoset materials have limitations in cycle times and recyclability, and recent advancements in thermoplastic-based composites are highlighted as a more sustainable and cost-effective option. The ability of thermoplastics to be melted and shaped repeatedly is noted as a significant advantage, as it allows for rapid forming technologies and potential for in-situ consolidation, which can reduce energy consumption and scrap, and increase recyclability and reparability. The use of ex-cellulose carbon fibers and renewable cellulosic precursors is suggested as a means of further reducing CO2 emissions and material costs, while increasing carbon fiber production on a global scale.

The adoption of multi-material concepts based on thermoplastic materials presents a promising solution for addressing the demanding requirements of the automotive sector. Although several strategies have been proposed for manufacturing such components, consolidation emerges as a preferred method due to its many advantages over competing technologies. Consolidation enables the development of both the composite and the dissimilar metal-composite joint in a single step, resulting in enhanced stress distribution, fatigue strength, and higher production rates without adding extra weight. To facilitate consolidation, advanced surface treatments are required on the metallic counterpart, and laser texturing is a highly effective method for achieving this purpose [3,4,5]. Extensively studied in several EU projects and currently at Technology Readiness Level 5 [6,7,8], laser texturing can be implemented either on-line or off-line, rendering it a versatile manufacturing strategy.

2.2.4 Extending service Life

In the context of the project, a comprehensive structural health monitoring (SHM) system incorporating piezoelectric and temperature sensors is developped. The integration of these sensors enables the detection and prediction of potential failures, providing valuable insights for maintenance and potentially prolonging the service life of the structure. The incorporation of these sensors is planned for all demonstrators, except for the cross car beam. Specifically, for the battery module, the sensors' busbars will be integrated into the battery module's housing, leading to cost, volume, and weight reductions.

2.3 End-of-Life strategies

The developed materials and processes in LEVIS are also geared to enable improved circularity in End-of-Life (EOL) strategies, to minimize waste, and to optimize reuse and recycling. Moreover, all structural parts are designed to enable simple and effective dismantling for repair, reuse and recycling of the components. By exploring different recycling methods, we hope to contribute to the development of more sustainable and eco-friendly composite materials.

2.3.1 Recovery of composite materials (debonding on demand)

The effective design of joints is crucial for achieving the potential weight reduction benefits of metal/composite assemblies. To this end, various joining technologies, such as adhesive tape layers, and surface treatments, such as laser texturing, have been employed. In recent years, interest has grown in developing joint interfaces with enhanced disassembly capabilities to improve recyclability and enable Maintenance, Repair, and Overhaul (MRO) activities. Controlled degradation mechanisms can be introduced into adhesives or intermediate layers added in one-shot processes to achieve this objective. In this regard, a novel on-demand disassembly technique based on induction heating has been proposed for metal-composite joints to optimize recovery and recyclability. The targeted TRL is expected to advance from TRL 4 to 5-6 following a thorough assessment of the state of the art.

2.3.2 Recycling of fibre-reinforced acrylic composite part

The recycling of CFRP presents significant challenges due to the low quality and yield of recycled materials, which makes it difficult to compete with virgin materials. Moreover, the recovered material properties may deteriorate due to chemical incompatibility or the presence of fillers, further limiting their potential reuse. Consequently, recycling CFRPs is heavily dependent on reintroducing recovered materials into the supply chain, and most composite materials are still disposed of or incinerated. However, incorporating thermoplastic resins in composites can facilitate better recovery and recycling of CFRPs.

In this project, we present two distinct recycling methods, namely pyrolysis and shredding, for recycling Carbon Fiber Reinforced Polymer (CFRP) materials. The pyrolysis method involves heating the CFRP in the absence of oxygen, thereby breaking down the resin matrix and recovering the carbon fibers, along with gas and oil byproducts. The oil and gas produced can serve as chemical feedstock for other processes. Despite the production of byproducts, the pyrolysis process is capable of retaining fibers with high mechanical properties [9]. For mechanical recycling, the fibers are shredded and incorporated into new composite materials.

2.4 Environmental and Economic Assessment

The environmental performance of newly designed EV components is benchmarked to current industry applications and assessed by means of Life Cycle Assessment (LCA). Life Cycle Costing (LCC) methodology is used to give cost insights on the material choices, production, manufacturing and EOL processes as opposed to their current equivalents, which indicates the financial feasibility.

A comparative (LCA) is carried out to benchmark the environmental performance of newly designed electric vehicle components against current industry applications. The LCA conforms to the framework outlined in the 14040-14044 standards established by the International Organization for Standardization [10]. The first step of the analysis involves defining a benchmark product and conducting a sustainability assessment. The benchmark product represents the current industry applications and serves as a reference for comparison. The sustainability assessment includes an evaluation of the benchmark product's environmental impact, covering the mining of materials, component production, product transportation, product use, and end-of-life processes. The LCA is not limited to greenhouse gas (GHG) emissions but includes emissions of hazardous or toxic particles and gases, naturally occurring and waste emissions resulting from extracting materials from the environment (e.g., crude oil and ores).

The newly designed EV components are then evaluated using the same LCA methodology as the benchmark product. However, the results of the LCA are preliminary, given that the technologies are in the early stages of development and the data provided by industry partners may not be representative of real-life industrial-sized applications. As a result, the LCA relies on laboratory-scale data, which often yields lower production per energy used, or calculations in order to simulate industry sized production. Future research aims to predict the environmental impact of industry-level applications of the new components, accounting for the larger scale of production and associated environmental impacts. This will involve collecting more comprehensive and representative data and using sophisticated modeling techniques to estimate the environmental impact of the new components. This will culminate in a sensitivity analysis as part of the LCA, taking into account the industrial level of the technologies and the impact of different electricity grid mixes and EV lifespans.

To assess the economic performance of the newly designed EV components, a comparative (LCC) analysis will be conducted to compare them to current industry applications. The LCC analysis determines the inventory analysis and system boundaries in the LCA. It evaluates the total cost of a product, process, or service over its entire life cycle, from raw material extraction to end-of-life disposal, and considers all costs associated with the product, including acquisition, operation, maintenance, and disposal costs. However, since the data was not yet available at the time of writing this paper, the LCC analysis has not yet been conducted.

3 Targets, results & lessons learned

This paper presents the set of lessons learned from the project by means of PESTEL categories. That means that we will categorize what we have learned in political, economic, sociocultural, technological, environmental, and legal factors. The conclusions presented in this paper are based on the results and analysis of the project as of March 2023. It should be noted that the project is still ongoing, and final adjustments, analysis and data that will follow in the upcoming year will not be considered in this paper.

3.1 Political

Environmental impacts of components can be affected by external background systems, such as policies, trends, and political changes that influence their operation. To address this challenge, designers can employ the iEDGE toolkit, which guides them in considering these changes during the early stages of the design phase. The first two steps of the toolkit are particularly useful, as they prompt designers to identify organizational objectives, societal trends and objectives, and compliance objectives. Additionally, the RiT checklist can aid in identifying potential bottlenecks for benchmark products or new designs that may arise from these changes or trends. Although the individual toolkit applications provide high-level guidance, they offer insights into societal objectives and trends that can serve as a foundation for the remainder of the design process (Fig. 2.).

Organisational objectives (Internal)	
A	Creating environment friendly and lightweight solutions
B	Contributing sustainability
C	Through usage of recyclable light metals
Trends and societal objectives	
D	Usage of renewable energy (solar panels, etc.)
E	Contributing innovation and cooperation/synergy with products developed
F	Usage of recycled materials, less energy and emission waste
Compliance objectives	
G	ISO 9001/ IATF 16949/ ISO 27001/ ISO 14001

Figure2: Objectives identified by the iEDGE toolkit in step 1: Framing the context [14]

During the sensitivity analysis of the first LCAs serving as benchmarks, the impact of different electricity grid mixes used to charge EVs is taken into consideration. This analysis aims to shed light on the potential implications of changes in national energy grid mixes on the environmental impact of EVs. While only the use phase of the EVs was considered for this sensitivity analysis, the implications could be relevant to all life cycle processes that consume electricity. The European Union (EU)-28 electricity grid mix was used as a baseline grid mix for comparison. On the other hand, the Chinese and United States (US) grid mixes were chosen due to their relatively large percentage of total energy consumption worldwide and significantly different energy source mixes. Specifically, the Chinese grid mix relies heavily on coal power, while the US relies on gas and nuclear power in addition to coal. In contrast, the EU-28 has the most diverse electricity grid mix [11].

The sensitivity analysis results for the battery module's different electricity grid mixes are shown in Table1. The emissions that had the largest impact on human health are presented in the table. It is worth noting that these results are for the entire life cycle of the component and not just the use phase. The analysis revealed that differences in electricity production could have a substantial influence on the study's outcomes, particularly regarding environmental impacts such as terrestrial acidification and fine particulate matter emissions. As previously mentioned, Chinese electricity grid mixes rely heavily on coal, which is a significant contributor to acidification and fine particulate matter emissions. Therefore, the results indicate that it is important to consider the electricity grid mix used to charge EVs, as it significantly affects the overall environmental impact of the EV components.

Table1: Results sensitivity analysis electricity grid mix battery module. [13]

	EU28		**CN**		**US**	
Climate change [kg CO2 eq.]	6,98E+00	100%	1,16E+01	166%	8,49E+00	122%
Fine Particulate Matter Formation [kg PM2.5 eq.]	3,87E-03	100%	8,95E-03	231%	3,81E-03	98%
Fossil depletion [kg oil eq.]	3,03E+00	100%	3,41E+00	113%	3,36E+00	111%
Terrestrial Acidification [kg SO2 eq.]	1,22E-02	100%	2,60E-02	213%	1,19E-02	98%

3.2 Economic

Given that the LCC has not yet been performed, this section will only discuss the results and observations derived from the eco-design toolkit. The qualitative outcomes of the toolkit will need to be validated by the LCC to assess their closeness to reality. The LCC results are anticipated to be presented in February 2024. The findings of the eco-design toolkit [14] indicate that the users identified KPIs related to the components' costs. The KPIs were mainly linked to production expenses and recycling returns (i.e., value of second-life components). The production cost targets were established to be similar to those of the benchmark products, while the recycling profit targets were set higher than the current solutions. The second stage of the iEDGE toolkit is centered on the EQFD, which determines the KPIs' importance. Remarkably, for most components, the economic KPIs were deemed less important when compared to the technical and environmental KPIs. Only for the Battery Box, did the recycling profits and the running costs of the vehicle (which is directly related to the component's weight) appear to be of high importance. This also resulted in the iEDGE toolkit not directing the users towards economic enhancements. This was evident in the scores given to the new design concept. Curiously, the only component expected to meet the economic targets was, in fact, the battery box.

3.3 Social

The iEDGE toolkit is concerned with integrating social objectives with economic, technical, and environmental considerations to make balanced decisions. Within the eco-design toolkit, the social focus area aims to assess the impact of the product or business operations on the workforce and local communities in the supply chain, with the goal of ensuring that production and use are ethically sound.

Results from the eco-design toolkits [14] and feedback from project partners indicate that the toolkit was effective in encouraging consideration of social design elements in addition to the other focus areas (economic, technical and environmental). However, the social area was found to be the least utilized, with most users identifying only one or two KPIs compared to three or four for other focus areas. The primary social KPI identified was related to safety during the manufacturing process. Given that the EQFD prioritized this KPI less frequently, it is not surprising that design improvements were not focused on the social aspect and did not result in any significant improvements in these areas.

3.4 Technological

The objective was to attain a weight reduction between 20-40% of the components in comparison to the benchmark product. The weight reductions aimed to not compromise the overall structural integrity of the components. The eco-design toolkit aims to facilitate users in making well-informed decisions, taking into account the four focus areas mentioned earlier. The technical KPIs that were established after the first two phases varied for each demonstrator. The final solutions per demonstrator, as well as their eco-design and lightweighting results are presented below, keeping in mind that the development of these components will continue until January 2024.

Suspension control arm:

The suspension control arm [Fig. 3.] is primarily composed of steel and aluminium inserts and bushings. The iEDGE toolkit identified several crucial technical KPIs, including durability, product weight, and safety monitoring, due to safety regulations requirements and project objectives. Specifically, the target was to achieve equal performance on durability and safety monitoring while reducing weight. To achieve this goal, the control arm body material was replaced with CFRP using acrylic-based resins and a combination of bio- and PAN-made carbon fibers via RTM manufacturing. The new design combines the bushings and ball joint into the control arm body via co-molding. The anticipated weight reduction for the new design is currently set to be approximately 26% without compromising structural integrity.

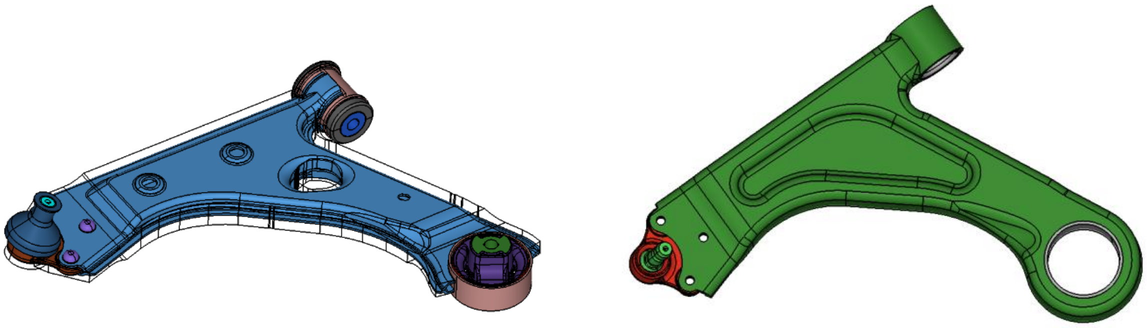


Figure3: Demo 1 - Suspension Control Arm (left: benchmark product, right: new design) [12]

Battery box:

The battery box (Fig. 4.) benchmark is predominantly constructed from aluminium. The iEDGE toolkit has identified several technical KPIs as important, including the sealing performance, density, and structural integrity. These factors are mainly driven by safety regulations requirements and project objectives. The iEDGE toolkit aims to achieve a higher score on all these KPIs.

To achieve the desired improvements, several solutions have been implemented. Firstly, a hybrid solution has been utilized to reduce weight in the structural beams. CFRP patches have been bonded to the beams to ensure that the structural integrity is maintained, while the aluminium structures themselves have been restructured to facilitate weight loss. Additionally, in the benchmark product, the upper cover is composed of a combination of aluminium and plastics. The new design, however, employs CFRP, with recycled carbon fibers used as reinforcement. These measures result in a weight reduction of around 31% without sacrificing structural integrity.

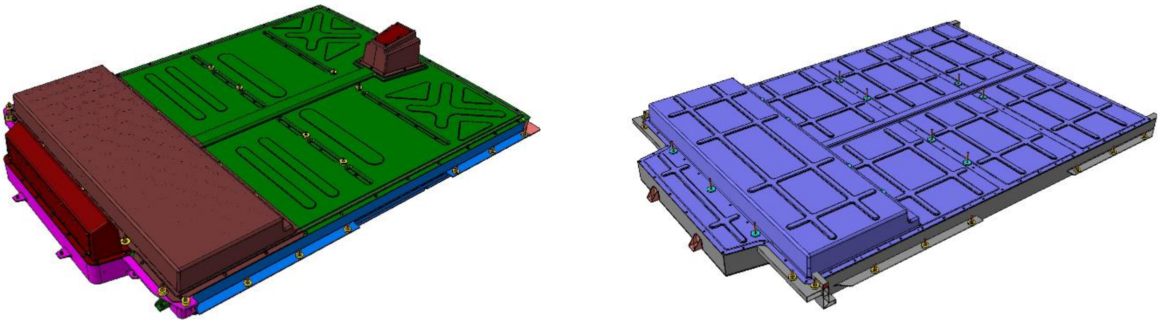
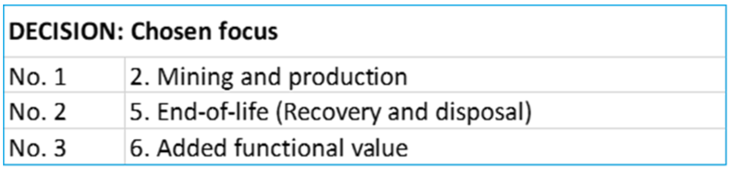


Figure4: Demo 2 - Battery Box (left: benchmark product, right: new design) [12]

Battery Module:

The primary function of the module is to store and distribute energy during the operation of the vehicle. The module housing serves as a mechanical casing for the cells, with its main function being to thermally, mechanically, and electrically protect the cells while ensuring electrical distribution through the busbar system. Additionally, the eco-design toolkit identified the estimated lifetime of the module, including second life, as a critical technical KPI, with EQFD highlighting this as a relatively high priority.

Using the KPIs and applying all the tools in the iEDGE toolkit, the design team identified three areas of improvement for the battery module (Fig. 5.). The benchmark design of the module consists of multiple pieces of plastics and epoxy glass. To address the identified areas of improvement, the new design is reshaped and features a modular box design made from Glass Fiber Reinforced Plastics (GFRP) that integrates sensoring into the casing and busbars.



DECISION: Chosen focus	
No. 1	2. Mining and production
No. 2	5. End-of-life (Recovery and disposal)
No. 3	6. Added functional value

Figure5: Suggested focus of improvement battery module [14]

By adopting the new design choices, the battery module meets all the suggested focus areas of improvement by the iEDGE toolkit. The optimized design allows for using fewer materials in the busbars and housing, leading to a reduced environmental impact in mining and production (2. Mining and production). Additionally, the modular concept enhances the ease of disassembly and end-of-life procedures (5. End-of-Life), further improving the sustainability of the EV. The addition of the sensoring in the design provides an additional functional value of the component itself (6. Added Functional Value). Ultimately, the new design choices result in a significant weight reduction of 47%.

Cross car beam:

The Cross Car Beam is a structural component located in the dashboard area of automobiles. In this project, the focus is solely on the steering column carrier (*Golden in Fig. 6.). KPIs for this component were identified, including the displacement, shake frequency, and weight of the carrier. These KPIs are crucial due to safety regulations and the objectives of the project. The target was set to achieve equal displacement and shake frequency while lowering the weight of the carrier.

The benchmark cross car beam is manufactured entirely from steel, with steel brackets welded to each other and to the main carrier pipe using MIG-MAG welding. The new design is a one-piece solid part that replaces several different parts of the steering column carrier. This new part is made from CFRP through injection molding and results in a 26% weight reduction. This new design structure successfully meets the technical target KPIs, enabling equal displacement and shake frequency while reducing the weight of the carrier.

Figure6: Demo 3 - Cross car beam (left: benchmark product, right: new design) [12]

3.5 Environmental

The aim of this study is to achieve a 25% reduction in GHG emissions at the component level through the use of new materials, manufacturing processes, reduced weight, and EoL strategies. The weight reduction targets for all the components have been met and the study seeks to determine the potential GHG emissions savings resulting from these changes. The preliminary results of the impact assessment on human health using the ReCiPe method are presented in Table 2. These impact categories have been identified as having the greatest impact on the life cycle of the benchmark products. It should be noted that these results are preliminary, and the final outcome of the life cycle assessment (LCA) may be influenced by design changes, additional data, and calculations. The final results of the LCA will be made publicly available in February 2024.

Table 2: Results LCA, life cycle emission savings of components in percentage. New design compared to benchmark product.

Savings	Suspension Control Arm	Battery Box	Battery Module	Cross Car Beam
Climate change (CO2 eq.)	-155%	64%	44%	-2%
Fine Particulate Matter Formation (PM2.5 eq.)	19%	82%	45%	56%
Human toxicity, cancer (1,4-DB eq.)	95%	60%	-42%	88%

Suspension control arm:

The GHG emissions of the suspension control arm have increased by 155% compared to the benchmark product, which is a substantial increase. The increase in GHG emissions is mainly attributed to the high manufacturing costs, such as the energy required for the production of carbon fibers, as well as the electricity and heat for the RTM process, all of which contribute significantly to the total amount of GHG emissions emitted during the life cycle of the suspensions control arm.

However, there are significant savings in emissions related to Fine Particulate Matter Formation (FPMF) and Human Toxicity (HT). These emissions are primarily emitted during the production of steel. Since most of the steel is replaced by CFRPs, these emissions are largely eliminated.

Battery box:

The battery box of an automotive vehicle has been analyzed to evaluate its environmental impact. The results indicate a significant decrease of 64% of GHG emissions over the entire life cycle. This reduction is mainly attributed to the manufacturing phase, with a decrease of emissions during the use phase also observed. The emissions during the production of the component (including mining of materials, etc.) of the battery box demonstrator are less than half of those emitted during the production of the benchmark product. The reduction in emissions can be attributed to several factors. Firstly, the demonstrator uses less material, including a lighter weight aluminum. Secondly, the location of origin of the aluminum extruded profiles used in the two products has a significant impact on the results. The benchmark product was manufactured in China and therefore relied on Chinese databases, whereas the demonstrator was produced in-house and used EU-28 databases. The electricity grid mixes from EU-28 produce fewer GHG emissions per kWh than Chinese grid mixes, which partially explains the differences observed.

The study also found large savings in the emissions of FPMF and HT. These emissions are mostly emitted during the production of aluminum, which was significantly reduced in the battery box demonstrator by replacing a large portion of aluminum with CFRPs.

Battery Module:

The battery module exhibits a significant reduction of 44% in GHG emissions throughout its life cycle, primarily stemming from the manufacturing phase. Although a portion of the savings is attributed to the use phase, the largest percentage of weight reduction between all components is from the battery module's design, hence contributing to its impact. Moreover, the new design's considerable reduction in copper mass, used for the busbar, significantly contributes to the emissions savings. However, the GFRP materials used for the module have the highest percentage contribution to GHG emissions during production, as indicated in Fig. 7. Specifically, PA6.6+glass fiber injection molding is the major source of GHG emissions during the production phase.

Similarly, there are substantial savings in FPMF emissions. Nonetheless, the battery module is the only component that exhibits an increase in human toxicity (HT) cancer emissions. According to the LCA results, this can be attributed to the use of PA6.6, which emits a relatively high amount of HT emissions compared to other materials employed in both the benchmark and demonstrator products.

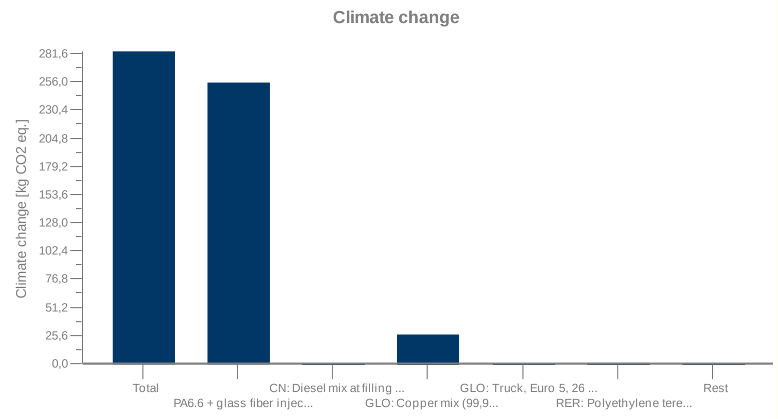


Figure 7: Impact on Climate Change (kg CO2 eq.) during the manufacturing phase of the battery module.

Cross car beam:

The cross car beam exhibits a marginal increase of 2% of GHG emissions throughout its entire life cycle. Although use phase emissions have decreased, manufacturing emissions have risen owing to the use of carbon fibers. The carbon fibers have a higher GHG emission rate compared to the steel used in the benchmark product.

Moreover, there are substantial savings in the FPMF and HT emissions. These emissions are mainly generated during the production of steel, and a significant portion of steel is replaced by CFRPs. As a result, these emissions are substantially reduced.

3.6 Legal

Through the integration of eco-design principles during the design phase, the products demonstrate increased resilience to future changes in legislation and regulations that promote a circular economy. In the same vein as the political category, the initial two stages of the eco-design toolkit aim to establish the parameters for the new design with respect to societal trends and regulatory compliance goals (Fig. 2.). Furthermore, the designer of the suspension control arm incorporated a KPI for "number of non-compliant parts" into the EQFD. However, the final results of the eco-design toolkit suggested that the new design would score lower than the benchmark product. Although the iEDGE toolkit did not identify this as a focus KPI, and as such the new design was not directed towards improving this specific aspect. Whether this represents an inherent limitation of the toolkit or whether concessions are simply part of the design process is a topic for further discussion.

3.7 Main conclusions

The adoption of the eco-design methodology and iEDGE toolkit was found to confer distinct benefits to the stakeholders involved and the design process of the prototypes. The application of these tools enabled the discovery of novel insights and knowledge, which assisted in the creation of more advanced design alternatives. Nevertheless, there exists ample scope for enhancing the usage and design of the toolkit to optimize the eco-design methodology. Introducing eco-design into the standard design procedure necessitates a greater investment of time and effort and requires familiarity with a new domain of expertise. Therefore, it is recommended that adequate resources and time be allocated to facilitate the integration of eco-design principles into the routine design process.

Regarding the developed technologies, it is premature to conclude whether all targets have been achieved at this stage of the project. While some demonstrators appear to have met their environmental objectives, others are expected to experience an increase in GHG emissions. Nevertheless, the final evaluation may differ upon incorporation of newly available data and calculations. The forthcoming sensitivity analysis will encompass factors such as industrialization, variations in electricity grid mixes, and other critical considerations. This will yield a comprehensive and refined depiction of the LCA's final results.

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